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FINAL REPORT

November 1952

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CHAPTER THREE

THE AIRGLOW

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## CHAPTER THREE

## THE AIRGLOW

## I. Introduction

The purpose of this report is to present some of the possibilities of scientific and technical intelligence which are contained in the study of the night and day airglows. This example was picked for several reasons, the principal one being that it is the last place where the conventional approach would lead one to look for significant intelligence results and leads. It has also been selected, because it is the field of upper atmospheric research in which the writer has been principally engaged, and to which he has made many basic contributions. It is believed that most readers will be as surprised as was the writer, at the number of intelligence results one can obtain. Most of the discussion will apply to the night airglow, about which we know much more than we do about daylight airglow. In order to give the reader some background for appreciating the intelligence aspects of this problem, we now introduce a brief description of the airglow problem.

## II. The Night Airglow

## I. Introduction

The first group of phenomena of the upper atmosphere to which we will direct attention, i.e. the airglow, are ones of which we should be most aware, since this awareness requires no complicated instrumentation. It has been known for centuries that the background of the night sky is not entirely dark, and the night airglow is the term which refers to that part of the diffuse light of the night sky which originates in the atmosphere of the earth. In the visible part of the spectrum the

total night airglow energy amounts to about five sixths of the total light of the night sky. It will not be necessary in the present report to discuss the twilight and day airglow.

## 2. The Spectra of the Night Airglow

The identification of the night airglow emissions really started in 1895, when the famous astronomer W. W. Campbell discovered visually the presence of the green line of atomic oxygen in the night sky. Since then, attempts to identify the night airglow emissions have met with great difficulties because of their faintness and because the spectrum is so complicated. Strangely enough, the relatively recent identifications of the night airglow emissions in the photographic infrared represents the best spectroscopy that has ever been done on this phenomenon.

The spectrum of the night airglow has been studied with varying success from the long wave-length limit of atmospheric ozone absorption at 3000 Å to about 10,000 Å. Probably, its most interesting characteristic is that the molecular and atomic excited states from which this radiation originates are generally the lowest ones. Another general result is that most of the spectrum originates on states from which transitions to the lower levels are highly forbidden.

These facts are very well illustrated by the presence in the spectrum of the Herzberg bands of O<sub>2</sub>, which originate on a 4.7 ev. level, and the Vegard-Kaplan bands of N<sub>2</sub>, which come from a 6.14 ev. excited state. Since the Herzberg bands have been observed in absorption, it is possible to estimate their transition probability, and while this is low compared with such radiations as the sodium yellow lines, it appears to be high compared with that of the Vegard-Kaplan bands. These bands were first observed in emission in the laboratory by Vegard in the phosphorescence of solid nitrogen, and by Kaplan, in both discharges

and afterglows in nitrogen. peculiarly enough, the Herzberg bands have never been obtained in emission in the laboratory, and the Vayard-Kapler bands have not yet been observed in absorption.

There are many other emissions, particularly in the 3000-5000 Å region, which have not been identified. Conclusively identified in the visible range are three atomic lines of oxygen and the sodium yellow lines. These lines originate on the lowest excited states of oxygen and sodium, a fact which is consistent with the low energies of lines of the molecular radiations. The oxygen lines are particularly interesting, because their levels of origin are the metastable states  $^1S$ , with a lifetime of 3.44 second, and  $^1D$ , with a 96-second lifetime. The corresponding atomic nitrogen lines are absent. We shall return to this later, when we discuss the implications of this observation.

The strongest molecular nitrogen radiations in electrical discharge in nitrogen are known as the first positive bands. These lie in the region from 5000 Å to 12,000 Å. Laboratory experience would suggest that emissions from the night airglow, which lie in this wavelength region would correspond to members of this system. It was to be expected, therefore, that many authors accepted this and ascribed these emissions to the first positive system. The correct identifications of these radiations came therefore as one of the greatest surprises in the history of night sky spectroscopy, and these represent the latest important contributions in this field.

The correct identifications of the night airglow emissions in the 7000-11,000 Å region can be said to have their beginning in independent observations by Meinel and Kaplan, the latter's observations having been made in laboratory sources.

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Kaplan (1947) discovered that the afterglow spectrum in oxygen consisted exclusively of bands from the excited vibrational state of the forbidden system of  $O_2$  which had long been known as the atmospheric system. It is a prominent feature of the solar spectrum because of the intense absorption of solar radiation by the oxygen in the atmosphere. The famous A and B bands, among others, in the solar spectrum are members of this system, and much had been learned about the oxygen molecule from high dispersion studies of these absorptions. The observations by Kaplan represented the first time that these radiations had ever been observed in emission.

Independently in 1949, Meinel discovered that one of the two bands observed by Kaplan was a prominent feature of the infrared spectrum of the night airglow. The band at 7600 Å, which is the so-called 0-0 band, is reabsorbed by  $O_2$  before it reaches the ground, while the 0-1 band at 6660 Å is observed. Recently, Krasovsky, working in Russia, observed the 0-2 band at 9976 Å, an accomplishment that must be noted with especial interest, when one realizes that the most intense infra-red emission at 10,640 Å, first observed by Stubbins, Mather and Oings in 1914, would require 1000 hours exposure of a hyperevacuumized Eastman I-I plate and an F/I spectrograph having a dispersion of 2000 Å/mm. Krasovsky accomplished his important observation using a prismatic spectrograph and a Cs-C-Ag electron image converter.

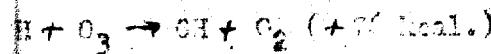
We now come to one of the most important and unusual spectroscopic discoveries of recent years. In 1950 Meinel discovered that the molecule OI gives rise to the prominent features of the night airglow spectrum in the photographic infrared. In cooperation with Herzberg, Meinel analyzed these radiations and showed conclusively that the emissions from 7000 to 9000 Å are due to the rotation-vibration spectrum of the

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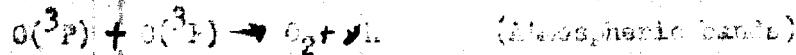
OH molecule. This situation is a remarkable one since these intense radiations are emitted by a minor constituent of the high atmosphere, and also because this identification marked the first time that a vibrational emission spectrum had been observed for a free radical.

In an excellent paper on the photochemistry of atmospheric water vapor, Bates and Nicolet showed that the most probable source of the visible OH bands in the night airglow is the two-body process

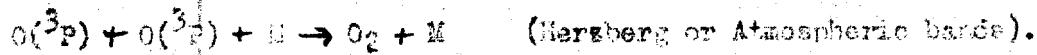


which is in accordance with the observed intensity pattern of the OH radiations. It should be noted that this reaction brings together two minor constituents of the atmosphere.

The atmospheric system of  $\text{O}_2$ , however, is probably emitted principally by the reaction in which atomic oxygen recombines to form a diatomic molecule. This process could proceed as follows:



or by three-body collisions,



Evidence from laboratory studies of the atmospheric system indicates that under laboratory conditions the three-body process is responsible for most of the radiation. Our understanding of these processes is extremely poor, and much laboratory work remains to be done.

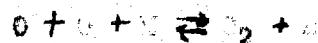
### 3. What Can We Learn From the Night (or Day) Airglow?

It is not necessary to be a specialist in chemical kinetics to realize that if the explanation of part of the night airglow luminescence as being due to the recombination of oxygen atoms to form oxygen molecules,

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and to the reaction between atomic hydrogen and ozone, is correct, that we have here an important tool for the study of reactions which may be of great technical importance. One needs only to read current literature in the field of spectroscopy and theory of various reactions, in particular of explosions and combustion, to realize this. In a paper as recent as that of Bates and Nicolat, which was referred to earlier, it is stated that the rate constant for the reaction



is not known. When one realizes the importance of such reactions to our knowledge of the composition of the upper atmosphere, including the ozone region, it is surprising that we don't have a complete knowledge of them.

The upper atmosphere, and the afterglow discovered by Laplan prior to the discovery of the atmospheric bands in the night-airglow emission, now provide us with two important sources of information about this reaction. The same importance can be ascribed, of course, to the reaction



which appears to be responsible for the OH radiations in the night airglow. Of particular interest is that the kind of spectrum, radiated by OH in the upper atmosphere, is important in the field of combustion, but was observed for the first time anywhere, in the upper atmosphere. This is a remarkable fact in itself, but an old experience to astrophysicists, who often observe things which have never been produced in laboratory sources. One must note carefully in passing that much of our knowledge in physics and chemistry has come to us by way of geophysical and astrophysical observations. A nation that recognizes this, and exploits it, will have a serious advantage over all other nations, even if the information is basic and unclassified as it should be. The habit of bringing

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science and technology close to Nature is a good one, and one that pays off, but one that is too easy to put aside.

In this very brief discussion, we have barely scratched the surface in our analysis of the things one can learn from the feeble light from our atmosphere, the night airglow. In the next section, we will try to indicate some speculative, yet reasonable results one might some day expect from night airglow studies. These ideas, as yet unpublished in other than Air Force reports and communications, are due entirely to the author.

#### b. Some Speculations

Each of the ideas and proposals which will be described in this section will apply to areas of science which have considerable military significance. It is interesting to note, as pointed out above, that these all grew out of work on such an eminently unpractical subject as the feeble night airglow.

##### a. Proposal for a possible new link between the Sun and the Earth's Atmosphere

The problem of finding some direct connection between atmospheric heating and circulation, and solar changes is an old and difficult one. It is difficult to know where the solution will come from, but it is certainly reasonable to state that a successful answer will change our entire picture of accurate long-range weather forecasts. The military significance of this would be remarkable.

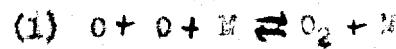
In Progress Report No. 1 of Contract No. AF19(60)-111, a proposed research program is outlined, the purpose of which is to test quantitatively the promise of a new heating mechanism in the region below 50 km., which it actually generates at a height of 80 km. by effects set up by variations in solar ultraviolet. The proposal is based on some

recent progress in the study of the night airglow. The contract referred to is under the direction of J. Kaplan, and the idea is original with him. A copy of the report is attached.

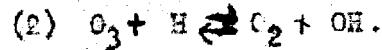
b. A method for estimating solar ultraviolet

It is a well known fact that surface, and even high altitude research stations cannot give us any knowledge of the Sun's short-wave radiation below 2900 Å. Most of the ozone in the earth's atmosphere lies above 20 km., so that equipment would have to rise well above this height in order to record the effects of ozone absorption. If it turns out then, that solar ultraviolet will be an extremely important factor in meteorological forecasting, how can we follow its variations? Shortly after the discovery by Kaplan of the O<sub>2</sub> atmospheric bands in emission, he proposed that a study of its intensity variations during the night, might reveal information regarding the total ultraviolet in certain regions of the spectrum, which had illuminated the atmosphere during the previous day.

Actually, since this original suggestion was made, it has been possible to photograph the day airglow spectrum from balloons, and it appears that an unusual amount of the spectrum falls in the infrared. It would be relatively simple to equip high level sounding equipment with photocells, which would tell us the intensity changes in the 6500-7000 Å region. Kaplan's suggestion is based on the fact that nearly all of the day or night airglow in this region is due to



or



The key to the connection between measured infrared and the ultraviolet that irradiates the atmosphere, is that the O, O<sub>3</sub> and H which are involved

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in reactions (1) and (2) are produced by the ultraviolet which is inaccessible because of ozone. The suggestion therefore shows how inaccessible ultraviolet can be measured by the accessible infrared.

### c. A new light source

The laboratory source in which the O<sub>2</sub> bands were first observed by Kaplan, is most remarkable for several reasons. It consists of an interrupted discharge in O<sub>2</sub>, followed by an extremely strong afterglow, whose radiation is practically monochromatic. No radiations other than two members of the atmospheric system at 7600 and 6640 have been observed. This means that observations on such a source can be made with economy and simplicity, because one needs no filters or spectrographic equipment of any kind.

Now the atmosphere, except for scattering, is transparent for 6640 and slightly opaque for 7600. By occulting the discharge mechanically, we have here a light source which can be used for many purposes. It is non-electronic. A problem which will be attacked shortly will be to investigate the maximum afterglow intensity. The decay characteristics of the afterglow depend on pressure, so that such a source can be easily coded.

### III. Comments on Russian Night Airglow Papers

There follow some comments on the two papers which were reviewed by H.E. in Kaplan's laboratory. The comments of H.K. follow those given here.

It will be noted that in the first paper, the authors thank Academician A. N. Terenin for his cooperation in the preparation of diffraction grating and replicas. Terenin is an outstanding physicist whose work has been known for thirty years. His principal interests are

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in photochemistry and optics. The prestige of night airglow work in the USSR must be high, if a man of Terenin's calibre takes an interest in it.

Now one must recognize that this interest in the chemistry of the upper atmosphere on the parts of Soviet scientists from other areas of science, may well be recent. In fact it may have been inspired by papers written by scientists in the United States, particularly those who specialize in airglow research. At any rate, it is worth pointing out that in 1949, two years after the first announcement of their discovery by Kaplan, two short papers appeared in the Journal of Chemical Physics, Volume 17, pages 220 and 221, on the photographic infra-red emission of O<sub>2</sub> from the O-O<sub>2</sub> flames. The authors were from the Applied Physics Laboratory of The Johns Hopkins University and from the Catholic University of America, respectively. No mention was made of the excitation of these bands by Kaplan, even though two of the authors are very good friends of Kaplan's. This shows that our experts in combustion spectroscopy do not read the literature in upper atmospheric chemistry. Very little has happened since 1949 to change this opinion. It will be interesting to look into this question at the Winter Meeting of the American Physical Society at Los Angeles, when there will be a symposium on spectroscopy of flames.

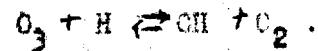
The reader will recall the important part played by Meinel in the clarification of our understanding of the infra-red portion of the night airglow spectrum. In the first of Krasovsky's two papers he claims that two Russians were the first to suggest that the vibration-rotational spectrum of OH was the source of most of this radiation. The two authors quoted are M. A. Ilyashovich and B. I. Stepanov. The authors gave Meinel credit for the work that he did.

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It is interesting to note that the Soviet writers disagree with the proposed explanation as given by Bates and Nicodet on the one hand, and independently by Hersberg, that the OH radiations originate in the reaction



Also interesting is the fact that they take a reasonably open-minded viewpoint, and that they suggested further experimental and theoretical studies. This is the first hint we have gotten of the possibility that their night-airglow studies are accompanied by laboratory and theoretical studies as well. It is only recently that we in the United States have extended our program in this area. Of course, the previously pointed out interest of Terenin, may indicate that other experts in spectroscopy are working on or are interested in night-airglow problems.

The Soviet claim to priority in the OH discovery is made plausible by the fact that reference is made in the second paper to the book on Spectroscopic Analysis of Reactions by V. N. Montratjev, published in 1944. This is one of the earliest published books in a field in which the U.S. is a relative newcomer. Also, Montratjev has made a special study of oxy-hydrogen flames, publishing many papers in 1936 and even earlier. The conclusion that the Soviets are aware of the value of night-airglow studies for the extremely practical problem of flames, is certainly tempting.

It is interesting to note that the Soviet writers have failed to recognize the presence in their excellent observations of the members of the O<sub>2</sub> atmospheric system. In fact, after making these remarkable observations in the far photographic infrared (9000-12,000 Å), it was J. Dufay who successfully identified the 9776 Å band as the (0,2) O<sub>2</sub> band of the atmospheric system. This is surprising when one considers that

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Konratjew's book was available to them, although there is no evidence that Konratjew himself is still active. He is really an able man in flame spectroscopy and kinetics, and in many ways anticipated the kind of work which is so popular and important here in the U.S. today.

- Somewhat surprising is the failure of Krasovskiy to refer to the two papers in the Journal of Chemical Physics to which we made reference earlier, relative to the failure of the latter authors to have known of the earlier discovery of the O<sub>2</sub> bands. In spite of this, it would be very important to try to evaluate recent Soviet work in flame and combustion spectroscopy, with some emphasis on its possible tie-in with the study of upper atmospheric radiations.

At first glance, Krasovskiy's disagreement with Bates and Nicolet appeared to be very badly founded. Further examination, however, revealed that it must be carefully considered, and not prematurely dismissed. If one tries to act as a fair judge, it is surprising what one can find in favor of the Soviet ideas. The problem is an important one, since Bates and Nicolet's beautiful paper in the Journal of Geophysical Research for September 1950, brings together the latest knowledge regarding the lower 100 km. of the atmosphere, and attempts to arrive at the vertical distribution of N<sub>2</sub>, NO<sub>2</sub>, OH, O<sub>3</sub>, H, O and O<sub>2</sub>O. This is an important problem. Also, the comparison between temperatures observed from rockets, and those from the O<sub>2</sub> and O<sub>3</sub> radiations, depends on a knowledge of the levels of emission for these radiations. The paper by Bates and Nicolet confirms an earlier qualitative prediction by Kaplan, and gives 60 km. as this level. This leads to excellent agreement with the rocket results, and focusses attention on the night airglow in the infrared as a trustworthy source of temperatures at about 60 km. Fortunately, as to the level of emission, Krasovskiy agrees with everyone else.

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Some of Krasovsky's criticisms of Bates and Nicolet are interesting. Their idea is that atomic oxygen in the two low lying metastable states, from which the well known green and red lines of the airglows originate, collides with  $H_2O$  and gives us excited OH radicals. According to them, the maximum energy of the OH radical, as observed in the airflow, is completely accounted for, while Krasovsky claims that Bates and Nicolet made an error when they failed to take into account the activation energy of the ozone-hydrogen reaction. This is an area of chemical kinetics in which available information is still quite incomplete, and one which is very important to our knowledge of fuels.

Bates and Nicolet base their ideas as to activation energies on a paper by Hirschfelder written in 1941, while Krasovsky refers to a Russian book on kinetics of oxidation reactions which was written in 1950. To compare the two, we calculated the activation energy of the  $H_2O + O \rightleftharpoons OH + OH$  reaction, using Hirschfelder's formula and obtained 6 kcal., while Zonratjev gives 22-24 kcal. The question is, does this difference represent better knowledge on the part of the Russians, since there is a definite difference between their results, and those found in available German and English books.

Kaplan has attempted to produce the OH bands in the laboratory under conditions which certainly appeared to have reproduced the Bates-Nicolet reaction. No real evidence was found for the presence of these bands. It is proposed to repeat these experiments. We propose also to try the one suggested by Krasovsky. Here it is interesting to note that such experiments, if successful will give us a test of Russian knowledge of chemical kinetics vs. ours. No one would expect this to come out of night-airglow studies.

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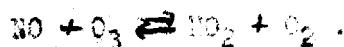
The most interesting part of Krassovsky's paper is his proposal that the radiations emitted in the reactions



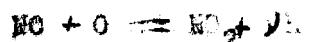
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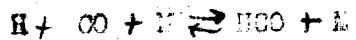
occur in the night airglow. Once again, the first impulse is to smile at their proposal, since they question the presence of certain members of the Vegard-Kaplan and Herzberg systems in the night airglow, and propose instead that they are HCO or  $\text{H}_2\text{CO}$  emissions. Actually, a careful examination of their proposals reveals that the suggestions are certainly worth looking into. Kaplan suggested that the molecule  $\text{NO}_2$  is responsible for some of the diffuse emission in the visible night airglow spectrum, in the reaction:



Recently, he concluded that the reaction



is also responsible for this emission. The resemblance between this and the



reaction is noteworthy. Once again, we derive an important suggestion for an experiment.

There are a number of other fairly tantalizing statements which indicate that Krassovsky and his associates are seriously studying basic processes in the atmosphere, and that in many places they are imaginative and quite up to date. Krassovsky's use of the Cs-O-Ag electron-image converter raises a question as to the quality of their infrared detection

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equipment. From the early days of Joffe, who was a pioneer in solid state physics, to the modern development of interest in the solid state, it is reasonable to expect the Russians to be quite competent. As already suggested in other communications with interested Air Force agencies, a test should be made to see if Krasovsky's converter was superior to ours. This should be relatively easy to do.

The striking thing about Krasovsky's bibliography is his failure to refer to the Journal of Geophysical Research, particularly to the paper by Bates and Nicoll. Either his reading habits have not included that important journal, or it is not available in the U.S.S.R. The author of references to books on chemical kinetics and to the spectroscopy of combustion is interesting. The fact that the books by Daydon and by Lewis and von Linde have been translated into Russian, and used by upper air physicists, is quite striking.

#### IV. Comments on Russian Scientific Papers — by H.K.

The papers referred to are the following:

- 1) Lukashenya, V. T., and V. I. Krasovsky, "Details of the Night Sky Spectra from 9500 Å to About 12,000 Å." Doklad. Akad. Nauk SSSR, Vol. LXIX, No. 2 (1951), p. 261.
- 2) Krasovsky, V. I., "The Effect of Water Vapors and Carbon and Nitrogen Oxides on Night Sky Luminescence." Doklad. Akad. Nauk SSSR, Vol. LXXVII, No. 4 (1951), p. 662.

The general impressions which can be obtained from these two papers are:

1. The Russian scientists are very active in studying the physics and chemistry of the upper atmosphere. These scientists have a

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comprehensive knowledge of the problems involved. In their pursuit of the solutions to the problems, they keep closely abreast with the foreign literature. Data papers, but in particular the second paper, written in 1951, quote some of the more important papers written in this country up to 1950, like: Kaplan, Phys. Rev., 70 (1950); Bates and Ecollet, Astr. Soc., 62 (1950); Seidel, Astrophys. J., 111 (1950); M. entec, Physica, 16 (1950); etc. Some of the more important books related to the field, have recently been translated into Russian, as, for example: Gaydon, "Spectroscopy and Combustion Theory"; Herzberg, "Atomic Spectra"; Huzel, "Molecular Spectra"; Whipple, "The Earth, Moon and Planets"; Lewis and Elbe, "Combustion, Flame and Explosion in Gases".

2. It is apparent from these papers that all the work which is being done serves a real and practical purpose. There seems to be a close cooperation between an administration who knows the practical significance of scientific research and the scientist who is made conscious of his importance by contributing to the effort of the whole.

Twice in his paper, does Krasovskiy mention the practical aspect of his research. He writes: "The above serves to show that the luminescence of the night sky has become a new means of analyzing and forecasting meteorological conditions"; and he ends his paper with the following sentence: "that the luminescence of the night sky is of immediate interest to the study of the ionosphere and is of definite practical value to such an investigation." Similar remarks have been found in the paper by Kozentilov on the "Structure of the Upper Layers of the Atmosphere" (1949), where the writer points out the importance of his investigation to "weather forecasts, long-range artillery, rocket aviation, and strategic reconnaissance."

From the scientific point of view, there might be some arguments between the Russian and the Western scientist as to the

17.

interpretation of certain phenomena observed in the sky. The identification and interpretation of the observed line at about 5777 Å has not been identified as resulting from O<sub>2</sub> and apparently enhanced by the strong OH band at 1,011. Å (J.,S.), the latter one properly quoted by the Russians. The mechanism for the formation of OH suggested by Krasovsky is not in agreement with the way by Datta and Nicolet. The discussion of the formation of HCO and H<sub>2</sub>CO in the atmosphere is very interesting. Formaldehyde (H<sub>2</sub>CO) has been reported to exist in the atmosphere of Venus by Wildt (1954), but has not been identified as a constituent of the terrestrial atmosphere, as far as the writer knows. Krasovsky shows a wave-length table for emission of the night sky, where he identified some of the Herzberg bands as possibly resulting from H<sub>2</sub>CO. It would be worthwhile to investigate this problem.

#### V. Some Research By-products (J.L. from here on)

It has taken more than a week to read and analyze these papers. The reason for this would be clear if we described all of the experiments that have been suggested during the preparation of this report. Several of them are already underway. The fact that such a process of analyzing these papers leads to important research problems, is excellent support for the suggestion in Section VI that every ARDC laboratory must have active contacts with the intelligence program. The time spent will be amply justified by the effect on the ARDC program.

One of the most exciting results from the study of these papers is that it leads to the performance of two experiments, which should be able to determine whether the Krasovsky or the Datta-Nicolet reactions are correct. In themselves, and as far as the usefulness of the night

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airflow for temperature determinations and for other studies he concerned, the decision is not too important. What is significant is that the Russians insist on a much larger activation energy than that used by us in the West. So the proposed experiments will give us a real clue as to the stage of development of chemical kinetics in the USSR.

#### VI. Some Lessons for Intelligence

One of the most important lessons to be learned from this report is that scientific intelligence, like research results in pure science, is obtained in many strange ways. By one agency, person, or method of operation will solve problems of scientific intelligence, any more than one person or method will solve a scientific problem. Intelligence results come from experiment and theory, just as do results in physics. They take time and patience, and as in other fields of Science, much money, time and effort are apparently wasted in the search for the results that never come. There is no short cut in this field any more than there is in Science.

It is not the purpose of this report to arrive at sweeping generalizations regarding Intelligence, rather it proposes to show how one man in one laboratory, can operate in the intelligence field. The results of this report can best be arrived at in a research setting. By this we mean in a laboratory in which library facilities, seminars, research activity, participation in symposia, contact with specialists, etc., are part of the mission of the organization. The Geophysical Research Division meets these requirements in an increasingly effective manner. The capable scientific intelligence officer, with experience in the actual problems of collecting and analyzing intelligence information, can act as the liaison between the laboratory and other intelligence

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agencies, both in the Air Force and elsewhere. We will not dismiss these other agencies or their problems.

This officer would be constantly alert to the potential intelligence value in seminars, symposia, scientific congresses, and in fact in the entire field of his particular laboratory. He would encourage members of the laboratory staff to think in terms of scientific intelligence requirements, and to volunteer requests for scientific intelligence information, as well as information which may help solve such problems of scientific intelligence as are known to the intelligence officer. This method would enable one man to form the knowledge and imagination of an entire laboratory on important problems of intelligence.

That these intelligence efforts, made by scientists in the laboratory, and by others who may be asked to help, can be made without serious hindrance on the primary functions of these scientists, has certainly been demonstrated in this report. In fact the opposite is true. New ideas for experiments and theoretical investigations are bound to grow out of each new approach to a topic, and the search for intelligence is such an approach.

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## ADDITIONAL

An interesting paper has appeared in the September 1, 1952 volume of the Physical Review. It is entitled "Resonance in Collision Processes," and its author is Prof. G. Oldenberg of Howard University. One of the principal aims of this paper is to criticize the over-emphasis that has occurred when physicists and chemists apply Franck's principle of resonance, requiring a minimum production of energy of translation, to triple collisions, and in particular to reactions of the Bates-Mosslet type referred to in this report.

This reaction explains the appearance of OH in the upper atmosphere with a maximum of 9 vibrational quanta. Oldenberg's argument leads to the conclusion that  $v = 9$  is presumably not preferred by resonance but is the maximum obtainable value of the vibrational energy stored in the OH radical. Oldenberg states to that it would be surprising if in the chemical rearrangement proposed by Bates and Mosslet, the total energy were to go into one degree of freedom, that is, into vibration of OH.

It is to be noted that Krasovskiy disagrees with the Bates-Mosslet proposal on the basis of calculations of the activation energy. The writer disagrees because of the failure of the OH radiations to occur in laboratory sources which closely approach the postulated conditions. Now Oldenberg criticizes the proposal on other theoretical grounds. This lends additional support to the conclusion that Krasovskiy may be correct, and that further laboratory studies are required to clear up this disagreement. It should be emphasized that from the intelligence point of view the important problem is to determine whether the Russians know more about the kinetics of chemical reactions than we do.

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Progress Report No. 1

METHODS AND RESULTS OF  
UPPER ATMOSPHERE RESEARCH

Contract No. AF19(604)-111

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University of California  
Institute of Geophysics

Progress Report No. 1  
May, 1952  
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The work reported herein is of a preliminary nature  
and the results are not necessarily in final form

Subject: Methods and Results of  
Upper Atmosphere Research

Project Director: J. Kaplan  
Report prepared by: J. Kaplan and H. K. Kallmann

May 15, 1952

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## ABSTRACT

An outline of the major problems to be investigated under the present contract is presented by the project director.

Planning and work in progress for a revision of Part I of the "Upper Atmosphere" report by Drs. F. A. Kelllogg and C. F. Schilling is discussed by Mrs. Gallmann. Emphasis is placed on the addition of information obtained from rocket research and its evaluation. It is suggested to enlarge the section on "emission from the sky". The proposed title for this part of the report is "Emission and Absorption in the Atmosphere". Furthermore, two new sections will be added to Part I of the report; namely a chapter on searchlight method and a chapter on the ozone layer.

152-19691

## I. OUTLINE OF RESEARCH PROBLEMS UNDER THE PRESENT CONTRACT

1. Work on this contract began on 1 April 1958. The first task, to which most of the effort is being applied, is the revision of the 1959 report on the Upper Atmosphere. The original report was prepared by Drs. W. W. Kellman and G. F. Schilling, and the revision will be carried out by Drs. W. W. Kellman and G. F. Schilling, and the revision will be carried out by Drs. W. W. Kellman and G. F. Schilling. Since the first report had favorably received, and the demands far exceeded the supply, it is suggested that this revision be prepared and distributed in large enough numbers to meet the demand. Otherwise, it might be desirable to consider a commercial publisher for the revision, with the approval of the Air Force and under conditions agreed upon with the sponsoring agency.

2. The review of recent work on the airglow has brought to light the following important problem, to which we shall direct special attention as a possible doctor's thesis for Mrs. Kellman. Following the discovery in 1946 by Kaplan of a strong afterglow in oxygen, whose spectrum consisted exclusively of bands from the  $v' = 0$  level of the forbidden  $^1\Sigma - ^3\Sigma$  state of  $O_2$ , Seinel found the (0,1) band in the spectrum of the night airglow, and recently, Krassovsky found the (0,2)  $O_2$  band. The (0,0) band is reabsorbed by the  $O_2$  below the emission layer. On noticing that the Kaplan-Seinel band 3640 (0,1) is a very variable feature, it occurred to one of us (J.A.), that this is a result of the variation in the amount and vertical distribution of atomic oxygen, possibly caused by variations in solar ultra-violet radiation which is responsible for producing the atomic oxygen. This sounds like a reasonable cause, since the 3640, 7600 and other atmospheric  $O_2$  emission-bands depend on the amounts and location of atomic oxygen. There may of course be vertical motions which bring atomic oxygen to lower levels, where they can recombine more readily, and thus radiate the atmospheric system. The relative importance of these effects will be studied as part of the work of this Contract.

The enhancement of the 7600 band, by whatever mechanism this may be accomplished, may have real meteorological significance for the atmosphere far below the level of emission of this radiation. As is well known, oxygen molecules

T52-19691

in the  $X^3\Sigma(v'' = 0)$  state will absorb the 7600  $\Omega_2$  radiation. An increase in its intensity, as revealed by Heinel's observation in the K-H band 8640, will mean increased absorption and heating of the  $O_2$  in the atmosphere. The amount of such heating, its distribution and possible dynamical effects, should be studied.

Another significant problem is the effect of this shifting of the atomic oxygen on the amount and distribution of  $O_3$ . It is not immediately apparent what this will be.

Under Contract AF19(122)-455, Mr. Harry Brook will attempt to study the mechanism of the recombination of oxygen atoms, which is responsible for the  $v' = 0$  phenomena. He hopes to obtain the rate constant for the reaction:



#### IX. INVORATIONS IN PROGRESS

With reference to the preceding outline by Dr. Kaplan, work is now in progress to revise and supplement Part I of the Upper Atmosphere Report, U. S. Weather Bureau - Contract Cwb 790h. In particular, Sections II, V, and VI of the report on "Methods and Results of Upper Atmosphere Research" will be brought up to date.

Section II deals with "rocket observations". Material has been collected from recent rocket research which will be added to this section. The information obtained from this source will result in a new temperature versus height curve, where the temperatures are consistently lower than the accepted values given in the NACA Standard Atmosphere Tables (1947). Experimentally determined pressure values up to an altitude of 120 km. and density values up to 160 km. have been obtained, thus making it possible to redetermine other atmospheric properties of interest, like velocity of sound, viscosity, collision frequency, etc.

Section V deals with "satellite observations". The latest results showing air densities or temperatures derived from meteor trails will be added. The

11/15/67  
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T52-19691

recent results obtained by Dr. Whipple's group from the Harvard Observatory and by Dr. Jacchia from the Harvard photographic program in New Mexico and of particular interest.

The title of Section VI, which reads "Emissions from the Sky," will be changed to "Emission and Absorption in the Upper Atmosphere." This section will be revised and supplemented by recent results obtained from spectroscopy. Observed results obtained with spectrographs flown in research rockets above the ozone layer, as well as twilight and aurora observations, will be included. Theoretical results and results obtained from laboratory studies will be added. More information about height and temperature of the emitting and absorbing layers will be in place. With respect to the latter problem an investigation of the prevailing theories and a comparison between theoretical and experimental results obtained, is very essential.

It is planned to add to the report a section on density measurements with the searchlight technique and a section on the ozone layer.

A literature survey for the different phases of the problem discussed in the preceding paragraphs is in progress now.

### III. PERSONNEL AND ADMINISTRATION

1. Appointment of Mrs. R. K. Kallmann as Graduate Research Physicist, Grade 2.

2. Request for permission for Dr. J. Kaplan and Mrs. R. K. Kallmann to attend meeting of the American Physical Society, June 30 through July 1-3, Denver, made 3 April 1952, and authorized by the Air Force Cambridge Research Center 22 April 1952.

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T52-19691